ATMOSPHERIC PREDICTABILITY

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LONG–TERM GOALS

To increase the understanding of the predictability of atmospheric processes as revealed by today's state–of–the–art atmospheric models, and to estimate the limits of atmospheric predictability.

OBJECTIVES

To foster collaboration in predictability research between the Institute for Meteorology and Geophysics (University of Vienna; http://www.univie.ac.at/) and the Naval Research Laboratory (NRL), Monterey, and the National Center for Atmospheric Research (NCAR; http://www.ucar.edu/ucar/), Boulder.

APPROACH

The first week of the trip was devoted to participating in two workshops held in Monterey, namely the **Predictability Workshop** (April 23–25, 2001), and the **THORPEX planning meeting** (April 26–27, 2001). During the **Predictability Workshop** several topics relevant for atmospheric predictability were discussed by workshop participants. The topics discussed were:

(1) Characteristics of Initial Perturbations that Influence Predictability,

(2) Rate of Perturbation Growth for Various Fields (this discussion facilitated by grant recipient),

(3) Characteristic Scales and Scale Interaction of Predictability Error Growth,

(4) Implied Limits of Prediction,

(5) Mechanisms of Error Growth,

(6) Effects of Model Error on Perturbation Growth.

Dr. R. M. Errico and Dr. R. Langland were among the Predictability Workshop organizers, Dr. C. Reynolds was one of the participants of the Predictability Workshop. Towards the end of the workshop the following questions were addressed:

(A) How do we use the information garnished from predictability studies to more effectively utilize and produce ensemble forecasts?

(B) How do we use the information garnished from predictability studies to more effectively optimize observing strategies, including targeting?

(C) How do we use the information garnished from predictability studies to more effectively set meaningful NWP research goals?

The **THORPEX planning meeting** was devoted to the presentation of key ideas and results relevant for a program science plan.

During the second half of the trip, the grant recipient carried out a **visit to NCAR** to continue and extend predictability research in collaboration with Dr. R. M. Errico. This research is largely based on NCAR's Mesocale Adjoint Modeling System (MAMS2; Errico et al. 1994; Errico and Raeder 1999). This visit to NCAR was in conjunction with the two ONR projects mentioned in the section "related projects".

TRAVEL COMPLETED

Table 1. Summary of visits conducted under this VSP.

Person Visited	Position	Institution/ Conference	Location	Scientific/ Technical Purpose	Dates (mm/dd/yy)
Rolf Langland	Scientist	NRL	Monterey	Workshop	$04/23 - 04/27/01$
Carolyn Reynolds	Scientist	NRL	Monterey	Workshop	$04/23 - 04/27/01$
Ronald M. Errico	Sen. Scientist	NCAR	Boulder	Collaboration	$04/28 - 05/02/01$

RESULTS

Part of the discussion at the **Predictability Workshop** focused on the rate of perturbation growth for various fields. Knowledge about the rate of perturbation/error growth is important because that rate implies – in the presence of initial/analysis error – a predictability limit. Evidence indicates that perturbations do amplify in global models – on average. Such amplification depends on the structure of the initial–time perturbation. Also, such amplification of perturbations in atmospheric models is taken for indicating that error growth is also a typical feature/inherent characteristic of the atmosphere (Leith 1978). In addition to growth of initial–time perturbations, Lorenz (1969) obtained the result that even if the larger scales could be observed perfectly, the inevitable uncertainties in the smaller

scales would after a day or so induce errors in the larger scales comparable to the larger–scale initial errors which presently result from inadequate observations; see also Leith and Kraichnan (1972).

Growth rates for global models can be estimated by observing how quickly initially nearby integrations diverge; i.e., how quickly the appropriately constructed difference between two model integrations grows. A useful measure are root–mean–square (rms) error-doubling times. Doubling times can be estimated from the difference of two forecasts valid for the same end time, but started, say, 24 hours apart. That difference may serve to estimate doubling times of 1–day forecast errors. To describe the growth of forecast differences, Lorenz (1982) has proposed the following model:

$$\frac{1}{E}\frac{dE}{dt} = \alpha \frac{E^* - E}{E^*} \ , \tag{1}$$

where E represents the rms difference between two initially slightly different forecasts, and E^* is a saturation value that is approached by E for large t; E^* takes into account that the separation of two model solutions is bounded. For small E ($E << E^*$), eq. (1) describes exponential growth with a doubling time equal to $\alpha^{-1}\ln 2$. The solution to eq. (1) with initial condition E_0 is given by:

$$E(t) = \frac{E^* \left(1 + \tanh\left[\frac{\alpha}{2}\left(t - t_0\right)\right]\right)}{\frac{E^*}{E_0}\left(1 - \tanh\left[\frac{\alpha}{2}\left(t - t_0\right)\right]\right) + 2\tanh\left[\frac{\alpha}{2}\left(t - t_0\right)\right]} \ . \tag{2}$$

This solution is shown in Fig. 1 for the initial condition $E_0 = 2^{-6}E^*$ with $\alpha = \ln 2/(2$ days) (corresponding to a doubling time of 2 days). The initial exponential growth, as well as the saturation at longer times are clearly visible from Fig. 1. In the workshop it was discussed extensively whether atmospheric error growth can be described in a meaningful way through a doubling time derived from eq. (1). That description provides a meaningful summary measure, but Dalcher and Kalnay (1987) also point towards the difficulty of estimating reliably that doubling time from available data; further, actual growth can be quite different for different synoptic situations and basic states.
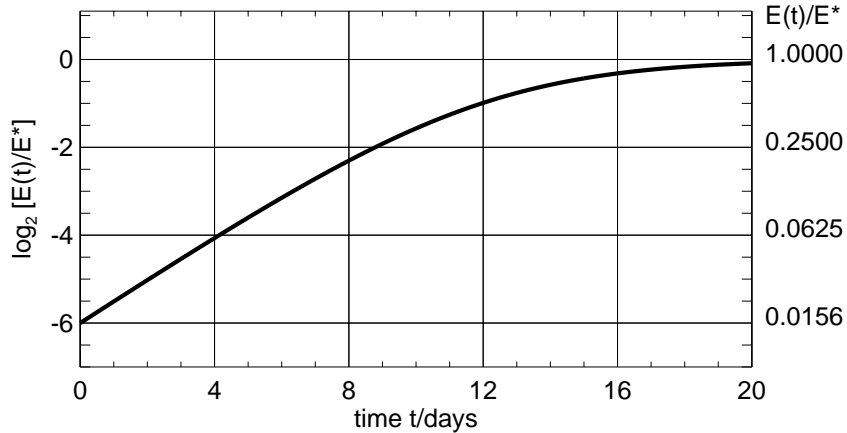

Figure 1: The solution of eq. (1) for $E_0 = 2^{-6}E^*$ and $\alpha = \ln 2/(2$ days).

On the basis of eq. (1), Simmons et al. (1995) have estimated error doubling times on the order of 1.5 days for 500 hPa geopotential height. They also show that errors grow faster at smaller scales. That value of 1.5 days was confirmed during the workshop and it is thought to be a stable predictability estimate for present–day forecasting systems. Doubling times for other parameters (e.g., precipitation) are, however, thought to be very different.

An example of the growth of forecast differences of 500 hPa geopotential height (in meters) within the European Centre for Medium-Range Weather Forecasts (ECMWF) prediction model during the winters of 1999 and 2001 is shown in Fig. 2. The forecast difference curves show an improvement in forecast consistency from 1999 to 2001. Perturbation growth rates are always smaller than growth of forecast error (in theory). That is, the difference between two model integrations grows slower than the difference between the model and an atmospheric analysis. It can be argued that the gap between the forecast error and the perturbation growth curve can be made smaller by further improving models (i.e., bringing forecast error down). However, inherent atmospheric error growth limits the scope for that improvement. Forecast error curves are also included in Fig. 2.
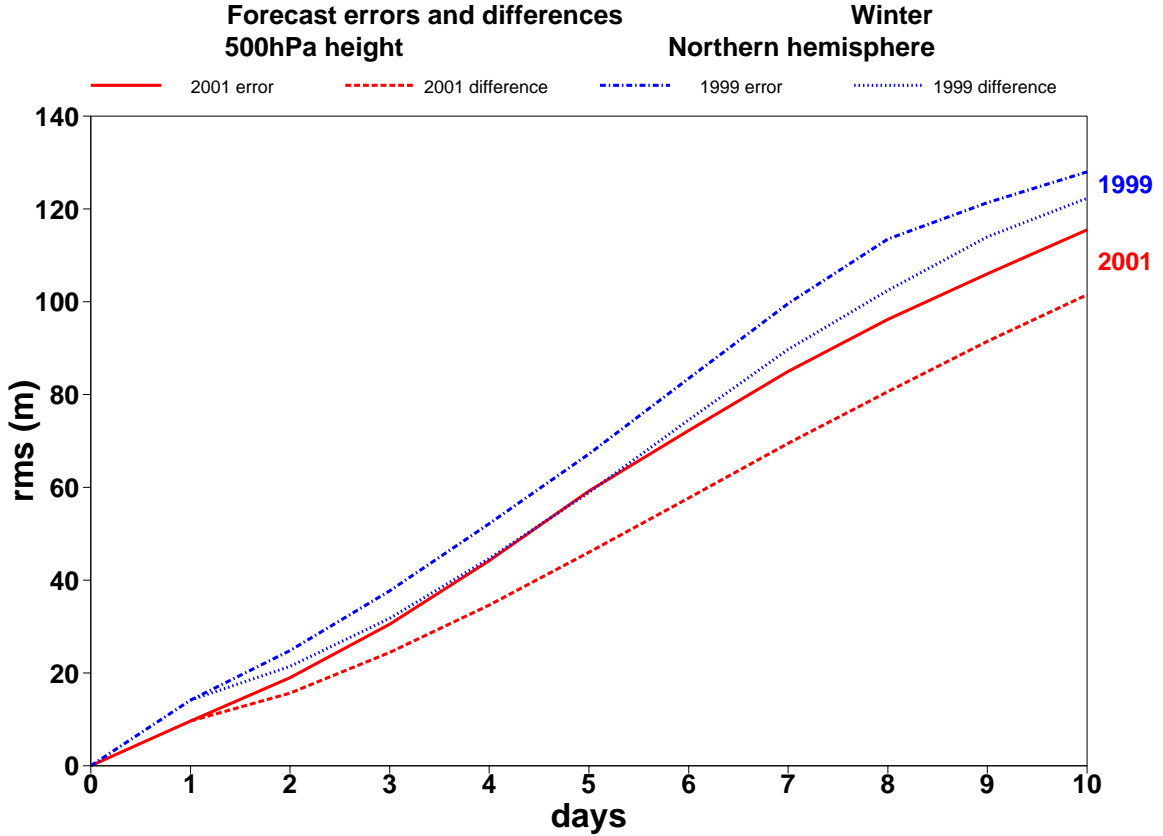

Figure 2: Growth of forecast errors (solid red for 2001, dash–dot blue for 1999) and forecast differences (short–dash red for 2001, dotted blue for 1999) of 500 hPa geopotential height (in meters) as a function of time within the European Centre for Medium-Range Weather Forecasts (ECMWF) prediction model during the winters of 1999 and 2001 (figure by courtesy of Dr. Adrian Simmons, ECMWF).

During the **visit to NCAR**, the grant recipient and Dr. R. M. Errico discussed recent predictability results obtained with MAMS2. The extension and discussion of preliminary results on the nature of singular vectors based on different initial– and final–time norms are expected to continue previous research (e.g., Errico et al. 2001). This collaboration is carried out in conjunction with ONR funded work.

IMPACT/APPLICATIONS

(a) improved understanding of atmospheric predictability with consequences for prediction of atmospheric conditions.

(b) closer collaboration between the University of Vienna and NRL and NCAR.

TRANSITIONS

A summary of the Predictability Workshop will be published in the Bulletin of the American Meteorological Society. The THORPEX planning meeting deliverable is a program Science Plan requested by the World Meteorological Organization. Ongoing work with Dr. R. M. Errico will be published in due course.

RELATED PROJECTS

The visit to Dr. R. M. Errico, NCAR, has been in connection with the following two ONR contracts: N00173-96-MP-0086 and N00014-99-1-0017.

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